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DEVELOPMENTS IN PETROLEUM REFINING TECHNOLOGY IN THE UNITED STATES, 1914-19

BY

A. J. KRAEMER

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DEVELOPMENTS IN PETROLEUM REFINING TECHNOLOGY IN THE UNITED STATES, 1914-19[1]

By A. J. Kraemer[2]

INTRODUCTION

Few important improvements other than the development of cracking processes were made in technical petroleum refining from 1914 to 1919. Refiners were concerned mainly with enlarging their plants and erecting new plants to meet the growing demand for petroleum products. Shell stills operated as a unit or arranged in series for progressive or continuous distillation were the prevailing distillation equipment. Some improvement was made in condensers, but in most refineries of the period coils of pipe immersed in tanks of water were used to condense vapors and cool liquid products of the stills. Heat exchangers to conserve heat and reduce costs were more highly developed at California topping plants than at other plants. In this connection Wadsworth[3] states:

> It is regretted that information concerning the operation of topping plants with eastern and Middle West oils is not available. The writer carefully canvassed the Middle West, but did not find a plant where operation had progressed beyond the early experimental stages and reliable figures could be furnished.

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7172."
This paper is one of a series on petroleum prepared at the request of the Energy Resources Committee of the National Resources Planning Board. Other papers in the series include Developments in the American Petroleum Industry, 1914-19, Exploration, Drilling, Production, and Transportation, by H. C. Fowler (Inf. Circ. 7171); Technical Research by the Bureau of Mines in Oil and Gas Production, Refining, and Utilization, by H. C. Miller and G. B. Shea, (Inf.Circ. 7173); Gains in Oil and Gas Production, Refining and Utilization Techniques, by H. C. Miller and G. B. Shea (published separately by the National Resources Planning Board as Technical Paper No. 3, 1941).
Work on manuscript completed May 1940.

2/ Senior refinery engineer, Bureau of Mines, Washington, D. C.

3/ Wadsworth, J. M., Removal of the Lighter Hydrocarbons from Petroleum by Continuous Distillation: Bureau of Mines Bull. 162, 1919, p. 2.

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Where heat exchangers were employed the hot residuum from the last still in a battery of continuous stills was passed through steel housings of rectangular or circular cross section containing pipes through which the cold oil was passed in the opposite direction on its way to the first still of the series. Frequently the oil was heated enough to obviate the necessity of firing the first still in the battery. Furthermore, in some California topping plants[4] heat exchange was employed not only to utilize the heat content of residuum but also to condense water and hydrocarbons vaporized in the distillation process.

This review of the developments of technology in petroleum refining during 1914-19 is based on the scanty information found in the literature for that period. Hardison[5] points out the inadequacy of such information in the following statement:

> Unlike the mining industry, technical literature of the oil industry is limited and extremely unsatisfactory. Until the recent efforts of the petroleum and Gas Committee of the American Institute of Mining Engineers, no concerted movement has been instituted to secure publication of papers dealing with problems of the oil business.

Although little was published during these years on oil-refining methods and practices, a review of the early petroleum bibliographies published by the Bureau of Mines[6] shows many technical articles dealing with laboratory studies of crude petroleum and petroleum products and with petroleum refining. In this brief article, however, no attempt will be made to review these papers, as they represent improved technology only in the embryonic stage.

CRACKING PROCESSES

Status of Cracking Processes, January 1, 1914

The desirability of decomposing hydrocarbons of high molecular weight to form compounds of lower molecular weight and greater volatility had been recognized many years before the period under review. Although cracking was still in its infancy at the end of 1919, the process was an important feature of the petroleum industry during that time. Commercial cracking was introduced in 1913, but in 1914 the cracking process for manufacture of motor fuel was used in only a few refineries.

4/ See footnote 3.

5/ Hardison, J. S., The Dehydrating Oil Plant of Nevada Petroleum Co., California: Trans. Am. Inst. Min. Eng., vol. 51, 1915, p. 627.

6/ Burroughs, E. H., Bibliography of Petroleum and Allied Substances for 1915: Bureau of Mines Bull. 149, 147 pp.; for 1916: Bull. 165, 159 pp.; for 1917: Bull. 180, 170 pp.; for 1918: Bull. 189, 180 pp.; for 1919 and 1920: Bull. 216, 374 pp.

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Rittman and his coworkers[7] reviewed briefly the various means for cracking oils that had been investigated, beginning with English Patent 3,345 issued December 27, 1865, to James Young, usually considered the starting point in a discussion of the subject. The record of the cracking patent case involving the Standard Oil Co. (Indiana) and other defendants[8] contains detailed discussions of many cracking patents.[9] Leslie[10] and Ellis and Meigs[11] also give much information on cracking processes.

Burton Cracking Process

The process known as the Burton cracking process, patented by William M. Burton and others of the Standard Oil Co. (Indiana),[12] was the only one in commercial operation at the beginning of 1914.

> The Burton process was the first commercially successful process for making gasoline by cracking, and in spite of intensive work by many other companies and individuals, for 6 or 7 years after its development it was the only commercially successful process. The Burton process was the first directly-fired pressure cracking process which was or could be run on a large scale to make a high percentage of gasoline and still maintain a black bottom (relatively cool bottom plate of the cracking still).[13]

In his address of acceptance of the Willard Gibbs medal for 1918, William M. Burton[14] said:

7/ Rittman, W. F., Dutton, C. B., and Dean, E. W., Manufacture of Gasoline and Benzene-Toluene from Petroleum and Other Hydrocarbons: Bureau of Mines Bull. 114, 1916, 267 pp.

8/ In the District Court of the United States, Northern District of Illinois, Eastern Division, United States of America vs. Standard Oil Co. (Indiana), et al, In Equity No. 4131.

9/ Brief of Defendant Standard Oil Co. (Indiana) on the Validity of Patents, 308 pp.

Technical Reference Book to Accompany Brief of Defendant Standard Oil Co. (Indiana) on the Validity of Patents, 381 pp.

10/ Leslie, E. H., Motor Fuels, Their Production and Technology: Chemical Catalog Co., New York, 1923, 681 pp.

11/ Ellis, Carleton, and Meigs, J. V., Gasoline and Other Motor Fuels: D. Van Nostrand Co., New York, 1921, 709 pp.

12/ Burton, W. M., Manufacture of Gasoline: U. S. Patent 1,049, 667, Jan. 7, 1913, Clark, E. M.: U. S. Patent 1,119,496, Dec. 1, 1914. Humphreys, R. E.: U. S. Patent 1,122,022, Dec. 22, 1914; and other patents.

13/ See footnote 9. Brief of Defendant, sec. 9.

14/ Burton, William M., Chemistry in the Petroleum Industry: Ind. and Eng. Chem., vol. 10, No. 6, June 1918, p. 486.

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> The first large [Burton cracking process] still we built had a charging capacity of 6,000 gallons of heavy oil, and by starting with fuel-oil products having boiling points ranging from 200° to 350° C. we were able to secure a very substantial yield of product having boiling points ranging from 50° up to 200° C.; and to our great gratification the losses incurred thereby were trifling, averaging less than 3 percent. We were astonished, also, to find that the high-boiling residues thus produced yielded a product almost identical with the natural asphalt which is mined in large quantities in the island of Trinidad. Evidently we are doing artifically what nature has done in ages gone by, viz., distilling petroleum under pressure.

In 1915 James[15] stated:

> The new system [Burton cracking process] has been installed at Neodesha, Sugar Creek, and Whiting, and is being installed at the Wood River refinery at Alton, Ill. The product by this system formerly was yellow and odorous, but these defects have been remedied.

Oildom (October 1916, p. 479) says:

> The Solar Refining Co. is installing 90 Burton stills for the production of gasoline. The Tidewater Oil Co. is expected by the end of the year to have 30 Burton stills in operation, with a total of 60 stills by June 1917. This will place the company among the largest gasoline producers in the country.

Thus, it appears that the Burton cracking-process operations attained significant proportions early in the period under review.

No estimates of the quantity of gasoline made by cracking in 1914 have been found in the literature. According to Van. H. Manning, Director of the Bureau of Mines,[16] however, the estimated "output of gasoline by the Burton process, the cracking process used by the Standard Oil companies, amounted in 1915 to 3,000,000 barrels."

The literature of the period indicates considerable opposition to cracked gasoline, and refiners were loath to admit that their marketed products contained cracked gasoline. This attitude was, of course, reversed in later years as it was found that cracked gasoline functioned as well as the straight-run product; with increased compression ratios of automobile engines cracked gasoline attained the position of a preferred product because of the absence of knocking in gasoline containing significant proportions of the cracked product.

15/ James, H. G., Comprehensive Review of Oil-Refining Conditions: Oil and Gas Jour., vol. 13, No. 44, Apr. 8, 1915, p. 17

16/ Preface to work cited in footnote 7.

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Rittman Cracking Process

Second to the Burton Process, the process developed by W. F. Rittman and his coworkers[17] received most attention in the trade press. The Rittman process was announced by Franklin K. Lane, Secretary of the Interior, on March 1, 1915.[18] The announcement stated that Dr. Walter F. Rittman, of the Bureau of Mines, had discovered a process that would greatly increase the production of gasoline and also produce benzol and toluol, chemicals used in making dyestuffs and high explosives.

Early in 1916 Van. H. Manning[19] stated:

> The U. S. Government is offering American refiners at no cost the right to make use of the Rittman process, which will increase the average amount of gasoline by not less than 20 percent, and to as high as 50 percent. Only ten refineries have accepted the offer. On February 1, 1916, seven refineries, in six States, were installing plants for the gasoline process. Benzene and toluene were being produced in large quantities by the other process.

In addition to the 10 licensees[20] of the Rittman process, applications for licenses were pending and other licenses were about to be issued. The process, however, was developed primarily to provide an additional source of benzene and toluene for the manufacture of munitions and did not prove successful in the modification intended for the manufacture of gasoline.

The lack of success of the Rittman process may be attributed to various factors. Although the large quantity of coke formed on the interior surfaces of the reaction vessels and the high temperatures and pressures employed undoubtedly were serious handicaps, the provisions of the licensing agreement may have had considerable restraining influence:[21]

> Although the use of the processes is to be free of charge to all citizens of the United States, it has been considered necessary for the protection of the basic patents, that licensees shall assign to the Secretary of the Interior, as trustee,

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17/ See footnote 7.

18/ National Petroleum News, Two Men Discover Similar Gasoline-Making Processes: Vol. 7, No. 1, March 1915, p. 1.

19/ Manning, Van. H., Petroleum Conservation Needed: Oildom, vol. 6, No. 4, April 1916, p. 165.

20/ Oildom (June 1916, p. 270) lists the following licensees of the Rittman process: Germania Refining Co., Oil City, Pa.; Pure Oil Co., Minneapolis, Minn.; Pittsburgh Oil Refining Co., Coraopolis, Pa.; Indian Refining Co., Lawrenceville, Ill.; Midwest Refining Co., Casper, Wyo.; American Oilfields Co. of California, Fellows, Calif., J. C. McDowell, Pittsburgh, Pa.; Associated Oil Co., San Francisco, Calif.; Benolite Co., Pittsburgh, Pa.; and Premier Oil Co., Los Angeles, Calif.

21/ Work cited in footnote 7, p. 131.

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> all patentable improvements, relating to the process, that may be developed by them, during the employment of the process. It is felt that if each licensee obtains the benefits of the improvements worked out by his colicensees, there is no particular hardship in his being compelled to turn over to the Government such improvements of a patentable character as may originate with himself or his employees. The justness of this condition, it is believed, will readily be recognized.

The agreement even stipulated[22] that "the cost of obtaining such letters patent, including the Patent Office fees, [are] to be paid by the second party [the licensee]." It was modified later by the Secretary of the Interior, but the change was not satisfactory to some prospective licensees.

Apparently the agreement did not protect licensees against litigation as to the validity of the patents on the Rittman process.

Leslie's[23] treatise, published in 1923, says of the Rittman process:

> Basic patents covering the Rittman process have not been issued as yet in this country but have been issued in England. Patents covering a number of features of the apparatus have been granted by the U. S. Patent Office. * * * So far as I am aware, the Rittman process is not being pushed today, mainly because of lack of a promotor. It is a good example of the stagnation that results when a process is free to all.

The 14 United States patents[24] listed by Leslie and Cross were issued between 1920 and 1923. The delay in issue of patents may have helped to retard commercial development of the process. In 1920, when the first patent on the Rittman process was issued, other processes had been developed and were on a production basis; and by 1922, when five additional patents were issued to Rittman in this country, cracking processes had developed even further.

Snelling "Synthetic Crude Oil" Process

The Snelling process probably received more attention in the petroleum trade journals of 1915 than any other cracking process except the Burton and Rittman processes. Snelling announced[25] his process at a meeting of the American Institute of Mining Engineers, February 14, 1915.

22/ Work cited in footnote 7, p. 132.
23/ Work cited in footnote 10, pp. 344, 345.
24/ Cross, Roy A., Handbook of Petroleum, Asphalt, and Natural Gas: Kansas City Testing Laboratory Bull. No. 25, Kansas City, Mo., 1928, p. 784.
25/ Snelling, W. O., Gasoline from "Synthetic" Crude Oil: Trans. Am. Inst. Min. Eng., 1915, vol. 51, pp. 657-671.

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He stated that it was discovered "in the course of some experiments more than 5 years ago made for a totally different purpose than the investigation of the oil used." A "synthetic crude oil" was made by placing in a bomblike vessel approximately one-fourth of its volume of lubricating oil, fuel oil, petrolatum, paraffin wax, or other petroleum fraction and heating to a temperature of approximately 800° F.; a pressure of about 800 pounds per square inch was thus generated. The vessel and contents were cooled, and the liquid product was subjected to fractional distillation. The resulting fractions comprised 15 percent of gasoline and 30 percent of burning oil, together with heavier liquid products, gas, and coke. The gasoline and kerosene distillates were clear and water white without treatment with acid or alkali and were free from the odor familiar in "cracked" petroleum distillates.

The process was owned jointly by Dr. Snelling and John T. Milliken, of the Milliken Refining Co., St. Louis, Mo. So far as can be learned, it was never operated on a commercial scale.

Leslie[26] says of the Snelling process: "The difficulty with methods that do not remove the products continuously lies in the low yield per cycle and the relatively long time required for cooling."

Aluminum Chloride Processes

The processes of A. M. McAfee[27] and G. W. Gray[28] apparently are adaptations of the process of Friedel and Crafts.[29] Bureau of Mines Bulletin 114[30] differentiates these processes as follows:

> Several processes have been devised for facilitating the cracking reaction at atmospheric pressure by adding aluminum chloride to the oils to be treated.
>
> The first process of this nature seems to have been that of Friedel and Crafts. From 5 to 20 percent of anhydrous aluminum chloride is added to the hydrocarbon material and the mixture heated in a still or other large retort to a temperature varying from 100° to 600° C. The process was designed to produce burning oils, lubricating oils, etc., from heavier

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26/ Work cited in footnote 10, p. 394.

27/ McAfee, A. M., Process of Improving Oils: U. S. Patent 1,127,465, February 9, 1915, and other patents; Improvement of High Boiling Petroleum Oils and the Manufacture of Gasoline as a Byproduct Therefrom by the Action of Aluminum Chloride: Ind. and Eng. Chem., vol. 7, 1915, pp. 737, 741.

28/ Gray, G. W., Method for Converting Higher-Boiling Petroleum Hydrocarbons into Lower-Boiling Petroleum Hydrocarbons: U. S. Patents 1,193,540 and 1,193,541, August 8, 1916.

29/ Friedel, Chas., and Crafts, J. M., Aluminum Chloride for Chemical Reactions: English Patent 4,769, December 15, 1877.

30/ Work cited in footnote 7, p. 14.

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hydrocarbons. Gasoline, of course, was not in demand at that time, so that the adaptability of the process for gasoline production was not mentioned, although clearly, in the light of later knowledge, the process is equally suitable for this purpose.

Gray, an American inventor, has patented a similar process with the addition of a mechanical stirrer, which keeps the aluminum chloride in suspension in the hydrocarbon material and prevents its being overheated. The mixture is heated to a temperature not higher than 163° to 177° C. Usually 5 to 10 percent of anhydrous aluminum chloride or other metallic chloride is used.

The more recently patented process of McAfee proposes the use of the same percentage admixture of aluminum chloride, as specified by Gray, and approximately the same temperatures (149° to 177° C.). No mechanical stirrer is used. A new feature is the use of a separate chamber between the still and the first condenser for the separation and recovery of the aluminum chloride.

The McAfee patent was assigned to the Gulf Refining Co., and a plant was built at Port Arthur, Tex., to operate under this process. Oildom (June 1916, p. 269) states:

The Gulf Refining Co. has denied the statement that it is to install the Rittman process, and states that it is perfectly satisfied with the McAfee process, which it has developed, and that it will install the process on an extensive scale.

Apparently considerable quantities of gasoline were made by the process, but, so far as can be learned, the process was never operated elsewhere than at the Port Arthur (Tex.) refinery of the Gulf Refining Co. Difficulties in the manufacture of aluminum chloride at low cost and of recovering aluminum chloride from the tarry residue of the process hindered its success. Several patents were issued to McAfee relating to the manufacture of aluminum chloride and its recovery from the residue.

Leslie[31] says of the McAfee and Gray processes:

The aluminum chloride processes have not been used in a large way as yet, though the Gulf Refining Co. at Port Arthur is still carrying on development work along this line under Dr. McAfee's direction, and the Texas Co. is doing likewise with the Gray process.

31/ Work cited in footnote 10, p. 382.

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Were it not for the cost of the aluminum chloride the McAfee and Gray processes would be widely used today because of the excellent quality of the product, and the avoidance of the use of pressure. On the basis of 60 pounds of aluminum chloride for every 100 gallons of heavy oil the production of each gallon of gasoline must be charged with the cost of 1.0 to 1-1/4 pounds of aluminum chloride.

Cross Cracking Process

The process patented by W. M. and Roy Cross[32] was the next after that of Burton in point of time to attain large commercial success. Although Oildom (June 1916, p. 269) stated that the Rosedale Refining Co., Rosedale, Kans., was building a Cross process plant, other references[33] indicate that the plant at the Lawrenceville, Ill., refinery of the Indian Refining Co. was the first commercial installation. A statement from Cross Cracking Process[34] follows:

In January 1921 one unit only was operating at the Indian Refining Co. at Lawrenceville, Ill., while at this time over 80 units are licensed to operate.

This pamphlet also carries the following legend under a halftone illustration:

The first experimental plant erected using the Cross process. This plant was built in 1915-16, and has a capacity of about 100 barrels of gasoline per day. On this plant nearly all of the experimental work was done.

Dubbs Cracking Process

The Dubbs cracking process apparently is the only one employed during 1914-19 that is still in operation.

Leslie[35] points out:

The Universal Oil Products Co. claims that the Burton process is an infringement on a patent[36] issued to Jesse A. Dubbs, and suit is pending [1922] in U. S. District Court at

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32/ Cross, Walter M., Process of Treating Hydrocarbons and Products Derived Therefrom: U. S. Patent 1,203,312, October 31, 1916, and other patents.
33/ Work cited in footnote 10, p. 376.
34/ Gasoline Products Co., Cross Cracking Process: Kansas City, Mo., August 1923, 16 pp.
35/ Work cited in footnote 10, p. 379.
36/ Dobbs, Jesse A., Treating Oil: U. S. Patent 1,123,502, January 5, 1915. (Application filed November 20, 1909.)

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Kansas City. A plant was built near Santa Barbara, Calif., in 1909, and an emulsified oil was dehydrated by the process of heating under pressure as described in the patent.

According to an extended account of the development of the Dubbs process[37] published in the Oil and Gas Journal, a demonstration run of a Dubbs cracking plant was made at Independence, Kans., on July 19, 1919, before a group of oil refiners. The unit had a daily charging capacity of about 80 barrels. The run was stopped at the end of 10 days, as had been agreed upon in advance - this period was considered ample to give conclusive results. The charging stock was gas oil. When the unit was opened after it had cooled the tubes were seen to be free from coke.

One reason for the success of the Dubbs process in contrast to the Rittman process may be found in the following statement of provisions of the Dubbs licensing agreement of 1919:[38]

> First, guarantee of the performance of the unit as to capacity and yield, with a provision which covered reimbursement of its cost to the refinery and removal of the unit from his plant if it failed to meet the guarantees.
>
> Second, unqualified guarantee to every licensee of immunity against the world from all charges of patent infringement. This includes not merely defense of litigation but also full protection against all loss through damages that might be assessed.

Other Cracking Processes

No doubt other processes were operated on a plant scale during the period 1914-19. However, no definite statements were found in the trade press to indicate that such was the case. Oildom (June 1916, p. 269) stated that Midwest refiners were installing plants on an extensive scale and gave the following list of refineries where plants were completed and in operation:

Cosden & Co., Tulsa, Okla.
Consolidated Oil & Refining Co., Cleveland, Okla., and East St. Louis, Ill.
Great Western Refining Co., Erie, Kans.
Sapulpa Refining Co., Sapulpa, Okla.
North American Refining Co., Pemeta, Okla.

It seems likely that the plants referred to were neither Rittman- nor Burton-process plants.

37/ Universal Oil Products Co.: Oil and Gas Jour., vol. 36, No. 2, May 27, 1937, p. U-12.
38/ See footnote 37.

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A large number of other cracking processes might be mentioned, but for the purposes of this brief review the three commercially successful processes (Burton, Cross, and Dubbs) that were started on a commercial scale during 1914-19, and the three relatively unsuccessful processes receiving most mention in the trade press (Rittman, Snelling, and McAfee), will indicate the trend of development. Other processes are discussed in the special treatises cited.39/

DEVELOPMENTS IN EXTRACTION OF GASOLINE FROM NATURAL HYDROCARBON GAS

During 1914-19 the volatile liquid product extracted from natural hydrocarbon gas was designated as "casinghead gasoline" because it was first extracted from casinghead gas, the gas produced between the tubing and the inner casing of oil wells, which rises in the well to the casinghead. The term "natural-gas gasoline" gradually came into use and was superseded by the term "natural gasoline." About 1921 the Association of Natural Gasoline Manufacturers adopted specifications for four grades of natural gasoline and four grades of motor natural gasoline (blends with petroleum naphtha to simulate straight-run gasoline made by distillation from crude petroleum).

The natural gasoline industry apparently started in Pennsylvania and West Virginia about 1903-04. One of the important early plants was built by John L. Gray about 1907-10.

Table 1 gives natural-gasoline production for 1914 to 1919, inclusive.

TABLE 1. - Production of natural gasoline in the United States, 1914-19.1/

Year	Plants	Gallons
1914.....	386	42,652,632
1915.....	414	65,364,665
1916.....	596	103,492,689
1917.....	886	217,884,104
1918.....	1,004	282,535,550
1919.....	1,191	351,535,026

1/ Geological Survey, U. S. Department of the Interior, Mineral Resources of the United States.

It is notable that the production in 1916 almost doubled that of 1915, and in 1917 more than doubled the production of 1916.

39/ Work cited in footnotes 7, 9, 10, and 11.

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Manufacture of natural gasoline during 1914-19 consisted essentially of extracting liquefiable vapors (and the gases dissolved in the liquid) from natural gas by compression, refrigeration, or absorption, or combinations of these procedures. The raw product of the extraction process was "stabilized" or "weathered" by keeping it in covered steel storage tanks without means of holding pressure on the tanks long enough to permit evaporation of the more volatile constituents.

The following discussion of natural-gasoline manufacture is based upon the treatise by Burrell.[40]

In 1905 William Mayburg, a retired preacher of New York, purchased a gas engine from the Bessemer Gas Engine Co. Later casual inquiry by that company disclosed that he was using the engine to operate a compressor for compressing casinghead gas to about 60 pounds pressure per square inch to extract its gasoline content. His plant was still operating about 1924, although considerably enlarged and somewhat remodeled. Mayburg's plant was therefore the forerunner of the high-pressure, compression, gasoline plants of the early twenties. These plants operated on essentially the same principle as the Mayburg plant; that is, they were equipped with a compressor to compress the gas, a prime mover to run the compressor, cooling coils, and a tank to collect the condensate. The first stabilizing columns (p. 16) were erected about 1923.

The Bessemer Gas Engine Co., immediately became interested in Mayburg's process, foreseeing in it a business that might grow and provide a market of consequence for gas engines and other machinery made by them. A large majority of the gas engines used in the compression method of extracting gasoline from natural gas were installed by that company. Pioneers in furnishing compressors for the work were the Ingersoll-Rand Co. The Bessemer Gas Engine Co. and Frank Peterson, who joined that firm in 1910 and studied problems of this new industry intensively, deserve much credit for establishing the industry on a firm commercial basis.

Absorption Process

While the compression method of extracting gasoline from natural gas was being perfected, another process, the oil absorption process, was being adapted to extract gasoline from so-called lean or dry natural gas. Dry natural gas does not contain enough gasoline to make it amenable to treatment by the compression method.

The oil-absorption process as practiced today involves the same principle as when invented in 1875 by William Young of Clippens, Renfrewshire, England, for extracting gasoline from gases produced in refining shale oil. Since then it has been used extensively in Europe

40/ Burrell, G. A., The Recovery of Gasoline from Natural Gas: Chem. Catalog Co., New York, 1925, 600 pp.

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for extracting benzol and toluol (light oil) from coal gas. The first installation for this purpose was made in the United States in 1898 by the Semet-Solvay Co., at Syracuse, N. Y.

The oil-absorption process consists in bringing natural gas in contact with an oil heavier than gasoline, whereupon the oil absorbs the gasoline. The oil is then pumped to a still and the gasoline distilled by means of heat. The stripped oil is pumped back to the absorbers to receive another charge of gasoline. The oil simply acts as a carrier of gasoline from the absorber to the still, where the gasoline is removed and the oil sent back again in an endless round of absorptions and distillations.

The first absorption work in the natural-gasoline industry was done by the Hope Natural Gas Co., a subsidiary of the Standard Oil Co of New Jersey, at Hastings, W. Va. Operations were begun at the plant in 1913.

The first low-pressure oil-absorption plant for processing casinghead (wet) gas was built in 1913 by the National Products Co., in the Cleveland oil pool, Oklahoma. The charcoal process for extracting gasoline from natural gasoline was initiated in 1918 with small-scale experiments by G. A. Burrell and G. G. Oberfell. It consists in passing natural gas into absorbers containing porous or "activated" charcoal ground to 8- to 14-mesh; this was used in gas masks during the World War. After the charcoal has absorbed its quota of gasoline, live steam is passed into the absorbers containing it and the gasoline is thus distilled out of the charcoal. The gasoline and steam are passed through condensers, where they are condensed and separated. Three absorbers filled with charcoal are used; in one the charcoal absorbs, in another natural gasoline is being distilled, and the third absorber is being cooled, the three operations taking place simultaneously.

The charcoal process did not achieve marked commercial success. According to Bureau of Mines statistics,[41] the 27 charcoal absorption plants operating in 1927 had a combined daily capacity of 214,000 gallons of natural gasoline, whereas 11 plants in 1937 had a combined daily capacity of 91,000 gallons.

Natural gasoline made by the oil-absorption process before stabilizers were introduced was more stable than that made by compression processes.

A natural evolution of the natural-gasoline industry was the combination of compression and absorption processes. By this procedure the residue gas from compression processes operated at relatively low pressures (100 psi) was passed into absorption plants to extract the remainder. The two portions of gasoline were combined to give a grade

41/ Hopkins, G. R., and Seeley, E. M., Natural-Gasoline Plants in the United States, January 1, 1938: Bureau of Mines Inf. Circ. 7031, 1938, 22 pp. For later information see Natural-Gasoline Plants in the United States, January 1, 1940: Bureau of Mines Inf. Circ. 7126, 1940, 21 pp.

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of gasoline less volatile than when only the compression process is used at higher pressures.

Engineers of the Bureau of Mines deserve special credit for discerning the potentialities of natural-gasoline extraction as a conservation practice as well as a profitable commercial undertaking. The following Bureau of Mines publications, issued from 1912 to 1919, directed attention to natural gasoline and the engineering practices recommended therein soon were adopted widely.

Technical Paper 10. Liquefied Products of Natural Gas: Their Properties and Uses, by I. C. Allen and G. A. Burrell. 1912. 23 pp.

Technical Paper 57. A Preliminary Report on the Utilization of Petroleum and Natural Gas in Wyoming, by W. R. Calvert, with a Discussion of the Suitability of Natural Gas for Making Gasoline, by G. A. Burrell. 1913. 23 pp.

Bulletin 88. The Condensation of Gasoline from Natural Gas, by G. A. Burrell, F. M. Seibert, and G. G. Oberfell. 1915. 106 pp.

Technical Paper 87. Methods of Testing Natural Gas for Gasoline Content, by G. A. Burrell and G. W. Jones. 1916. 26 pp.

Bulletin 120. Extraction of Gasoline from Natural Gas by Absorption Methods, by G. A. Burrell, P. M. Biddison, and G. G. Oberfell. 1917. 71 pp. (Delivered first in May 1916, as a paper before the Natural Gas Association of America.)

Bulletin 151. Recovery of Gasoline from Natural Gas by Compression and Refrigeration, by W. P. Dykema. 1918. 123 pp.

Bulletin 176. Recent Developments in the Absorption Process for Recovering Gasoline from Natural Gas, by W. P. Dykema. 1919. 90 pp.

In addition to the Government reports listed, many Bureau articles on the subject were published in technical journals and presented before meetings of scientific and technical organizations. In this way much information was placed directly before those most interested and was made available to the industry at the earliest possible date (exemplified by Bulletin 120).

Elaborate fractionating columns or "stabilizers" operating under pressure were not used commercially until about 1923. By this practice the result accomplished by the earlier process of "weathering" to free the natural gasoline of dissolved gases and volatile liquids was achieved in a manner to control the volatility of the finished product and to conserve the volatile material that formerly escaped to the air. The use of stabilizers made possible the large-scale development of the liquefied petroleum-gas undustry, as these gases now are obtained solely from such stabilizers either at natural-gasoline plants or petroleum refineries.

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However, Zanetti,[42] in 1916, remarked that the fraction from natural gas containing propane and the butanes in some places is condensed with ethane by further compression of the "wet gas" after the first gasoline condensate has been formed. The material was put up in steel cylinders for use as an illuminant or for welding with oxygen.

OIL SHALE IN 1914-19

During the period under review interest in oil shale as a source of liquid fuels was enhanced by fear of imminent shortage of petroleum. Many projects for utilizing oil shale were undertaken, but none of these efforts proved commercially important. Gavin[43] gives a good review of the early history of oil-shale developments in the United States.

Oil-Shale Studies of the Bureau of Mines

In 1916 the Bureau of Mines decided to study the technologic and economic aspects of oil shales of the United States as a supplement to petroleum. The investigations were interrupted by the entrance of the United States into the World War but were resumed early in 1919. Conditions in the petroleum industry of the United States in 1916 regarding available supply of petroleum and facilities for supplying demands differed from those prevailing in recent years. The future possibilities of petroleum supply, particularly from the standpoint of meeting the rapidly increasing demand for gasoline, were questions of much concern.

Reports of the Geological Survey,[44] Department of the Interior, had established definitely that the oil-shale deposits were of immense magnitude and that their potential oil yield was many times greater than the total quantity of petroleum that had been produced from the oil fields of the United States.

The reasons for investigating oil shale as a source of an adequate and dependable supply of liquid fuel were: (1) The adequacy of the supply was beyond question; (2) the oil in shales is not fugitive, as is petroleum; and (3) there is little danger of the shale deteriorating or altering in place.

42/ Zanetti, J. E., The Thermal Decomposition of the Propane-Butane Fraction from Natural Gas Condensate. Ind. Eng. Chem., vol. 8, No. 8, pp. 674-678, August 1916.

43/ Gavin, M. J., Oil Shale - A Historical, Technical, and Economic Study. Bureau of Mines Bull. 210, 1924, 201 pp.

44/ Woodruff, E. G., and Day, D. T., Oil Shale of Northwestern Colorado and Northeastern Utah: Geol. Survey Bull. 581 (a), 1914, pp. I-21.

Winchester, D. E., Oil Shale in Northwestern Colorado and Adjacent Areas: Geol. Survey Bull. 641 (f), 1916, pp. 139-198; Oil Shale of the Uinta Basin, Northeastern Utah, and Results of Dry Distillation of Miscellaneous Shale Samples: Geol. Survey Bull. 691 (b) 1918, pp. 27-55.

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The judgment of the Bureau of Mines engineers in deciding to study oil shales received substantial support in the executive order signed December 6, 1916, by President Wilson, establishing two Naval Oil-Shale Reserves to be held for the exclusive use or benefit of the United States Navy.

In July 1917 a chemical engineer of the Petroleum Division, Bureau of Mines, in a trip through the oil-shale fields of Colorado and Utah collected information on the companies, proposed methods of retorting, and details of some special types of retorts. Samples of shales from various districts in this country were tested for their oil content, and a résumé of the oil-shale industry was compiled.

The Bureau of Mines study of oil shales and shale oils may be divided into two periods. During the first, from the beginning of the work in 1916 to 1925, various problems involved in commercial development of oil-shale utilization were studied. These studies were limited to laboratory work, field surveys, and economic discussions based on the data then available pertaining to development of a future oil-shale industry in the United States.

During this period much valuable fundamental information was obtained, and the groundwork was laid for the second period of the Bureau's work beginning in 1925, when the scope of the study was expanded from laboratory scale to experimental operation with units of commercial size on Naval Oil-Shale Reserves in Colorado. These operations were terminated and the plant was dismantled June 30, 1929. The Bureau has done no experimental work on oil shale since the large-scale tests were discontinued.

Quality of Gasoline Marketed in the United States

In 1915 the Bureau of Mines made a gasoline survey[45] and in 1917 and 1919 extended the work.[46] The method used in distillation analysis of the samples taken during the 1915 survey differed considerably from that used in the surveys of 1917 and 1919. Therefore, comparison of results of the latter surveys with the earlier one can only be approximate. The average dry point (maximum temperature indicated by the thermometer in the laboratory distillation) reported for the 247 samples in the 1917 survey was 394° F., and the corresponding point for the 851 samples in the 1919 survey was 423° F. These dry points were markedly higher than the corresponding values for the 52 samples of gasoline included in the 1915 survey, most of which probably were below 350° F.

45/ Rittman, W. F., Jacobs, W. A., and Dean, E. W., Physical and Chemical Properties of Gasoline Sold Throughout the United States During the Calendar Year 1915: Bureau of Mines Tech. Paper 163, 1916, 45 pp.

46/ Hill, H. H., and Dean, E. W., Quality of Gasoline Marketed in the United States: Bureau of Mines Bull. 191, 1921, 275 pp.

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The increase in maximum boiling point of gasolines from 1915 to 1917 and from 1917 to 1919 probably reflected increased demands for gasoline during that period. To meet these demands the supply was increased to some extent by including in gasoline larger proportions of petroleum distillate that formerly was marketed in the kerosene fraction and by blending kerosene with natural gasoline--the production of which increased markedly from 1914 to 1919 (table 1)— but largely by increased production of crude petroleum and consequent enlargement of refining operations.

Federal Specifications for Petroleum Products

Under date of July 31, 1918, President Wilson issued an order to the United States Fuel Administrator to prepare specifications for petroleum products and to proceed to this end by means of a Committee on Standardization of Petroleum Specifications. The first bulletin of this Committee, which was published in October 1918, contained among others a specification for motor gasoline. The gasoline specification of October 1918 consisted principally of a distillation test and a general statement on quality. This generally is known as the "Navy specification" because it was originated by the Navy Department and had been used by that Department for some time before its adoption by the Committee.

The specification of October 1918 was revised, effective November 25, 1919. The revision also required only one test, the distillation range, which was somewhat more lenient than the earlier test. Federal specifications for gasoline and other petroleum products have been revised from time to time since 1918.

E. W. Dean,[47] petroleum chemist of the Bureau of Mines, reviewed the status of petroleum refining early in 1919. An abstract of his paper follows:

> The paper presents information relative to the efficiency of petroleum refinery practice of the time. The Bureau of Mines is sufficiently acquainted with the subject to realize the inadequacy of the data upon which discussion must be based. The figures given are actually nothing more than a series of rough estimates.
>
> The several most important ways in which the petroleum refining industry could increase the output of gasoline from a given quantity of crude oil were: (1) Universal adoption of a high "end point" or upper volatility limit for gasoline; (2) general use of more efficient distillation methods and

47/ Dean, E. W., Present Status of Refinery Practice in the United States with Regard to Gasoline Production: Oil and Gas Jour., vol. 17, No. 38, 1919, pp. 52-53. Presented before New York Sec., Soc. Automotive Eng., February 16, 1919.

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equipment; (3) recovery of gasoline now lost in refinery operations, and (4) wide use of cracking processes. There was one other possibility - the refining of crude petroleum now marketed as fuel oil without removing its naphtha content. The Bureau had not, however, succeeded in uncovering statistical evidence indicating that developments in this line could augment production by a maximum of more than 3 to 5 percent of the quantity of gasoline then refined.

End points of usual grades of motor fuel were between the limits of 392° and 446° F., and gasoline with end points as high as 446° F. was being used in tremendous quantity and with satisfactory results. The Bureau could not go on record at that time as either advocating or approving such a standard.

The distillation equipment employed by petroleum refiners did not operate with the same degree of efficiency that was being attained in some other industries. However, many refiners were maintaining as high a degree of distillation efficiency as was profitable under existing commercial conditions. The probability seemed to be that efficiency in gasoline recovery ranged in different refineries between the limits of 75 and 95 percent. It was improbable that the Nation's supply of gasoline would be increased more than about 10 percent through advances in the technique of large-scale distillation.

Bureau of Mines statistics of the time showed that an average of about 4 percent of the crude oil treated was lost in the course of refinery operations. Part of this loss was inevitable, but part represented gasoline that escaped with refinery gases. No doubt extraction of gasoline from refinery gases eventually would become a general practice.

The wider use of cracking processes was without doubt the most promising means by which refiners could increase the output of gasoline from a given amount of petroleum. In order to apply the cracking process to the extent necessary to double gasoline production, the limitations apparent at that time in the class of processes to which the Burton process belonged would have to be obviated.

The ratio between the market prices of gasoline and fuel oil was important in expansion of cracking operations. If the demand for fuel oil exceeds the supply, its price is bound to rise and the margin of profit of cracking processes would be wiped out.

Refiners may be able to augment production of gasoline by 25 to 30 percent exclusive of the gains possible through wider application of cracking. The wider use of cracking processes may permit further increases up to a possible additional 100 percent.

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Dean's article seems to support the conclusion that petroleum refining methods did not improve markedly, from the technologic viewpoint, during the period 1914 to 1919 and indicates the reasons for the absence of notable improvements in technology. A higher degree of fractionating efficiency would not have been profitable. The Burton cracking process had inherent limitations that inhibited its growth. The stability of a profitable ratio between the price of gasoline and fuel oil was doubtful.

However, the major reason for the slight improvement in technology was probably the urge to supply increased demands and to utilize the increased production of crude petroleum. New refineries were being built as rapidly as possible and consequently differed only in minor details from those most recently built. Undoubtedly minor improvements were made, particularly in successive refineries built by the same company, but no radical changes were made during this period.

The foregoing review of developments in petroleum refining, cracking, natural-gasoline manufacture, and oil-shale technology seems to indicate that no technologic developments were of sufficient magnitude to account for the increased production of gasoline and other petroleum products from 1914 to 1919. Evidently the reason for the increase must be sought in some other direction than in the field of technologic improvements. The following section of this report is an analysis of the available statistics on changes in number and capacity of petroleum refineries in the United States between 1914 and the end of 1919.

Productive Capacity of Petroleum Refineries, 1914-19

Table 2 is a compilation of available data on geographical distribution and capacity of petroleum refineries in the United States in 1914 and at the end of the years 1918 and 1919. Table 3 summarizes the data in table 2 to emphasize the regional changes in petroleum refining during the period under review.

The data seem to indicate clearly that the major change in petroleum refining during this time was simply growth. Apparently no important technologic development caused production of gasoline and other petroleum products to increase between 1914 and 1919 other than the larger number of petroleum refineries in 1919 and consequent greater aggregate capacity to refine crude petroleum. Refiners cut more deeply into the crude oil charged to stills in making gasoline in 1919 than in 1914, but they were competent and had the facilities to cut as deeply in 1914 as they did in 1919 if conditions had warranted doing so. No technologic change was necessary.

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TABLE 2. - Petroleum refineries in the United States, 1914, 1918, and 1919

District and State	1914[1] Number of plants	Dec. 31, 1918[2] Number of plants	Dec. 31, 1918[2] Capacity, barrels per day	Dec. 31, 1919[2] Number of plants	Dec. 31, 1919[2] Capacity, barrels per day	Dec. 31, 1919[2] Plants being built	Dec. 31, 1919[2] Capacity, barrels per day
East Coast:							
Georgia	-	-	-	1	4,000	-	-
S. Carolina	-	-	-	-	-	1	7,500
Maryland	3	4	15,500	4	15,500	-	-
Pennsylvania	4	4	51,130	4	53,630	-	-
New Jersey	8	4	100,000	7	110,500	1	5,000
New York	3	4	23,000	4	23,000	-	-
Massachusetts	-	-	-	-	-	2	15,000
Rhode Island	-	-	-	-	-	1	10,000
	18	16	189,630	20	206,630	5	37,500
Appalachian:							
New York	3	3	11,500	2	8,000	-	-
Pennsylvania	44	44	39,805	52	48,545	2	-
West Virginia	4	5	7,700	5	7,900	-	-
Ohio	1	1	400	1	400	-	-
	52	53	58,405	60	64,845	2	-
Central:							
Ohio	6	9	23,960	9	24,100	2	13,000
Indiana	1	2	36,500	3	47,200	1	3,000
Illinois	9	11	46,000	14	58,000	-	-
Kentucky	-	2	2,600	6	11,700	2	-
Tennessee	-	-	-	1	500	-	-
Minnesota	-	1	300	1	1,500	-	-
	16	25	109,360	34	143,000	5	16,000

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TABLE 2. - Petroleum refineries in the United States, 1914, 1918, and 1919. - Cont.

District and State	1914[1]	Dec. 31, 1918[2]		Dec. 31, 1919[2]			
	Number of plants	Number of plants	Capacity, barrels per day	Number of plants	Capacity, barrels per day	Plants being built	Capacity, barrels per day
Mid-Continent:							
Oklahoma.....	24	79	233,300	87	248,900	17	[3]22,850
Kansas.....	13	31	71,350	33	80,200	3	-
North Texas.....	5	18	66,350	48	143,450	43	123,300
North Louisiana.	-	4	5,365	5	10,500	6	11,200
Arkansas.....	-	1	300	1	600	-	-
Missouri.....	1	5	16,375	4	15,775	1	1,000
Nebraska.....	-	-	-	1	500	1	1,000
	43	138	393,040	179	499,925	70	159,350
Gulf Coast:							
South Texas.....	6	8	145,700	16	173,350	7	18,100
South Louisiana.	1	8	62,560	8	62,095	3	17,000
	7	16	208,260	24	235,445	10	35,100
Rocky Mountain:							
Colorado.....	4	2	1,500	3	1,700	-	-
Utah.....	-	1	800	1	4,200	1	500
Wyoming.....	2	5	52,250	10	61,000	4	11,500
	6	8	54,550	14	66,900	5	12,000
California.....	42	37	280,870	41	310,320	1	-
United States:							
Total.....	184	293	1,294,115	372	1,527,065	99	[4]259,950

1/ Bureau of the Census, U. S. Department of Commerce, Census of Manufactures, 1914.
2/ Bureau of Mines, U. S. Department of the Interior.
3/ 12 refineries; capacity not reported for 5 refineries.
4/ This figure applies to 89 refineries; capacity not reported for 10 refineries.

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TABLE 3. - Petroleum refineries in the United States, 1914, 1918, and 1919, by districts

District	1914[1]	Dec. 31, 1918[2]		Dec. 31, 1919[2]			
	Number of plants	Number of plants	Capacity, barrels per day	Number of plants	Capacity, barrels per day	Plants being built	Capacity, barrels per day
East Coast.....	18	16	189,630	20	206,630	5	37,500
Appalachian.....	52	53	58,405	60	64,845	2	-
Central.....	16	25	109,360	34	143,000	5	16,000
Mid-Continent....	43	138	393,040	179	499,925	70	159,350
Gulf Coast.....	7	16	208,260	24	235,445	10	35,100
Rocky Mountain...	6	8	54,550	14	66,900	5	12,000
California.....	42	37	280,870	41	310,320	1	-
	184	293	1,294,115	372	1,527,065	99	3/ 259,950

1/ Bureau of the Census, Department of Commerce, Census of Manufactures, 1914.
2/ Bureau of Mines, U. S. Department of the Interior.
3/ This figure applies to 89 refineries; capacity not reported for 10 refineries.

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Petroleum-refining facilities were not increased abruptly in 1914 or from 1914 to 1919. The Bureau of the Census reports: 48/

> The industry advanced steadily during the 35 years (1879-1914), the amount of petroleum refined in 1914 being nearly 11 times as great and the cost of materials and value of products being over 9 times as great as in 1879. The greatest actual increase during any of the 5-year periods appears for 1909-14, though the industry showed marked development during each period.

48/ Bureau of the Census, Census of Manufactures, 1914, Petroleum Refining.

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